

# Visual Imagery: Effects of Short- and Long-Term Memory

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## Abstract

■ Visual imagery and perception share several functional properties and apparently share common underlying brain structures. A main approach to the scientific study of visual imagery is exploring the effects of mental imagery on perceptual processes. Previous studies have shown that visual imagery interferes with perception (Perky effect). Recently we have shown a direct facilitatory effect of visual imagery on visual perception. In an attempt to differentiate the conditions under

which visual imagery interferes or facilitates visual perception, we designed new experimental paradigms, using detection tasks of a Gabor target. We found that imagery-induced interference and facilitation are memory-dependent: Visual recall of common objects from long-term memory can interfere with perception, while on short-term memory tasks facilitation can be obtained. These results support the distinction between low-level and structural representations in visual memory. ■

## INTRODUCTION

Visual imagery and perception share several functional properties and apparently share common underlying brain structures. The involvement of cortical structures common to visual imagery and perception is supported by studies on evoked potentials (Farah, Peronnet, & Gonon, 1988), regional cerebral blood flow (Goldenberg et al., 1989), positron emission tomography (Kosslyn et al., 1993; Kosslyn, Thompson, Kim, & Alpert, 1995; Roland, Eriksson, Stone-Elander, & Widen, 1987; Roland and Gulyas, 1995), and functional magnetic resonance imaging (LeBihan et al., 1993). Neuropsychological case studies have provided support for the hypothesis that visual imagery and perception share the same neural substrate (Bisiach & Luzzatti, 1978; Mehta, Newcombe, & DeHaan, 1992), yet brain-damaged patients with double dissociation between imagery and perception may reflect the fact that the visual areas subserving visual imagery are a subset of those active in visual perception (Behrmann, Winocur, & Moscovitch, 1992; Jankowiak, Kinsbourne, Shalev, & Bachman, 1992). Data indicating activity in early visual areas during visual imagery suggest that identical visual areas subserve both systems (LeBihan et al., 1993; Kosslyn et al., 1995). However, these areas are not activated during visual imagery in all subjects and are activated mainly by tasks that require high-resolution images (Roland & Gulyas, 1994; Sakai & Miyashita, 1994).

A main approach to the scientific study of visual imagery is exploring the effects of mental imagery on perceptual processes. What are the interactions between imagery and perception? An early study by Perky (1910)

reported a curious phenomenon. When subjects were told to imagine looking at an object (such as a banana) on a supposedly blank screen while actually being shown a faint picture of the object, they sometimes confused the picture with the image of the imagined object (Perky, 1910). The so-called Perky effect is defined as the reduction in performance from the no-imagery to the imagery condition. Evidence that visual, as opposed to nonvisual, imagery can impair visual perception, was reported by Segal and Fusella (1970). Subjects were presented with faint geometric forms or auditory tones as target stimuli while imagining other objects or sounds. Using the method of signal detection, they found that perceptual sensitivity was maximally reduced when the modality of the image matched that of the target. For instance, it was harder to detect a faint geometric form when imagining a visual scene than when imagining a familiar sound (Segal & Fusella, 1970). Other findings show that imagery interferes with performance in various visual tasks (Segal, 1971).

Craver-Lemley and Reeves (1987) have explored the imagery-induced interference with a vernier acuity task in which observers had to report whether the bottom line was offset to the left or the right of the top line. The results have shown that imagery of vertical or horizontal lines, and even of a gray mist, affected performance, but only when the image overlapped or was very close to the target (Craver-Lemley & Reeves, 1987). At which of several levels of processing might the Perky effect occur: optical, response organization, sensory, perceptual, or attentional? Craver-Lemley and Reeves (1992) reviewed different types of explanations of the Perky effect. Opti-

cal factors such as fixation, pupil size, and accommodation failed to explain the imagery-induced interference, as did shifts in criteria for responding in imagery, or demand characteristics. Perceptual and sensory explanations, such as assimilation (that is, parts of the stimulus are assimilated into, or fused with, the mental image) and masking (images reduce acuity by mimicking the effects of real-lines masks), did not account for the Perky effect. Diversion of attention (the withdrawal of attention from the visual task to the image) also could not explain the Perky effect. Craver-Lemley and Reeves concluded that imagery reduces visual acuity by reducing sensitivity—that is, imagery reduces the target energy in the region of the visual field where the images are located (Craver-Lemley & Reeves, 1992). Recently, Craver-Lemley, Arterberry, & Reeves (1997) have reported that the interference was found to be specific to the depth plane—accuracy for the target decreased when an image was projected in front of, but not behind, the target.

Although there is ample evidence that imagery can interfere with like-modality perception, there is also evidence that it can facilitate perception. Neisser (1976) has proposed that images generally function as perceptual “anticipations”—imagining an object would speed up perception by initiating the appropriate perceptual processes in advance (Neisser, 1976). Farah (1985) has carried out experiments that support the anticipation hypothesis. By imagining letters of the alphabet (H and T) that match presented letters, the ability to detect the letters increased. The subjects were more accurate in detecting the letters when the images matched the targets in both shape and location relative to the control condition, in which detection was performed without imagery (Farah, 1985). However, the facilitation effect was probably due to a spatially localized shift of criterion rather than to a change in sensitivity (Farah, 1989). Thus, facilitation may reflect processes other than changes in visual sensitivity.

McDermott and Roediger (1994) have reported that imagery can promote priming on implicit memory tests. When subjects were given words during a study phase and asked to form mental images of corresponding pictures, more priming was obtained on a picture fragment identification test compared to a study phase in which subjects performed semantic analyses of the words. Imagery produced selective facilitation—imagining *pictures* primed picture fragment identification but not word fragment completion, whereas imagining *words* primed word fragment completion but not picture fragment identification. The authors concluded that imagery is perceptual in nature; that is, imagery engages some of the same mechanisms used in perception and thereby produces priming (McDermott & Roediger, 1994).

Recently, we have reported a direct facilitatory effect of visual imagery on perception (Ishai & Sagi, 1995, 1997) by using a lateral masking detection paradigm developed by Polat and Sagi (1993). In this paradigm, the

effect of two mask stimuli on the perception of a target stimulus is measured using a simultaneous masking. Since localization of stimuli is crucial for exploring spatial interactions, Gabor signals were chosen as target and masks. A Gabor signal is a sine or cosine periodic luminance modulation within a Gaussian envelope (Gabor, 1946), assumed to minimize joint localization in space and spatial frequency and to evoke optimal response from simple cells in the primary visual cortex (Pollen & Ronner, 1983). Observers performed a detection task of a foveal Gabor target, either while perceiving flanking Gabor masks placed at different eccentricities or while imagining the absent masks. We have reported that when observers performed alternating tasks of perception and imagery, a threshold reduction was seen in both tasks. This imagery-induced facilitation shared the same characteristics with the perceptual facilitation (Ishai & Sagi, 1995) and was subserved by a stimulus-specific short-term memory trace for orientation and eye used (Ishai & Sagi, 1997). *Visual noise* and orientation-specific memory masking interfered with the accumulation of the trace (Ishai & Sagi, 1995, 1997). Neither facilitation nor interference were obtained when observers generated Gabor signal images from long-term memory. These results indicate the existence of common representational structures that can be used by both perception and image generation, and they provide psychophysical evidence for primary visual cortex activation during visual imagery.

Finke (1986) has tried to sort out the conflicting findings on image facilitation and interference by employing two different types of tasks. In the *identification* task, subjects had to indicate on each trial whether a horizontal or vertical bar had been presented. On most trials, the subjects were instructed, in advance of presentation, to visualize a bar that was horizontal, vertical, or at some intermediate orientation. In comparison with their performance on control trials, in which subjects were told not to form an image, they needed less time to identify bars when the imagined and presented bars were perfectly aligned and more time when the imagined bars were oriented in between the target bar orientations. In the *detection* task, the subjects merely reported whether either of the two bars had been presented, without having to identify them. In this case, reaction time increased as the imagined and presented bars became more closely aligned, in contrast to the results for the identification task. Thus, concluded Finke, whether imagery facilitates or interferes with performance on a perceptual task depends not only on whether the image matches the target but also on the nature of the task (Finke, 1986). As we have recently reported, visual imagery can facilitate detection of a visual target (Ishai & Sagi, 1995, 1997); therefore the nature of the task could not account for the interactions between imagery and perception.

In an attempt to understand the interactions between

visual imagery and perception, we designed new experiments to explore the conditions under which visual imagery interferes with or facilitates visual perception. We report here an orientation-specific imagery-induced interference, which is mediated by recall of common objects (lines) from long-term memory. When retrieval is based on short-term memory, no interference is seen. These results suggest that both imagery-induced facilitation and interference are memory-dependent (and not task-dependent) and support the distinction between low-level and abstract descriptions in visual memory.

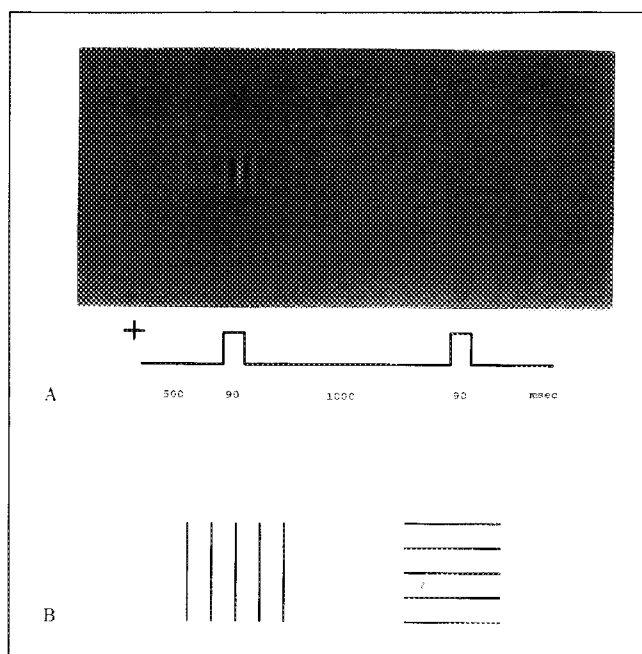
## RESULTS

### Experiment 1: Imagery-Induced Interference

Craver-Lemley and Reeves (1987, 1992) have shown, using a vernier acuity task, a reduction in performance due to imagery of vertical or horizontal lines, providing the image covered the target. In an attempt to obtain a Perky effect, an experiment was designed in which observers had to detect a vertical Gabor target under the following three conditions: control, imagery of vertical lines, and imagery of horizontal lines (Figure 1). Before the imagery experiments, observers were presented with a picture of vertical and horizontal lines (see Figure 1). The results were surprising (Figure 2). A suppressive effect of 0.1 logarithmic unit was obtained when observers imagined *vertical* lines, yet imagery of horizontal lines did not affect target threshold. The differences between imagery of horizontal lines and control conditions were not statistically significant, but the differences between imagery of vertical lines and control were significant, as were the differences between imagery of vertical and horizontal lines (repeated measures analysis of variance, followed by Scheffe multiple comparison,  $p < 0.01$ ). This imagery-driven orientation-specific interference, seen for the first time with detection of a Gabor target, could have been due to the imaginary lines or to recall from long-term memory, as opposed to the imaginary Gabor signal and short-term memory tasks that were previously shown to facilitate perception (Ishai & Sagi, 1995, 1997).

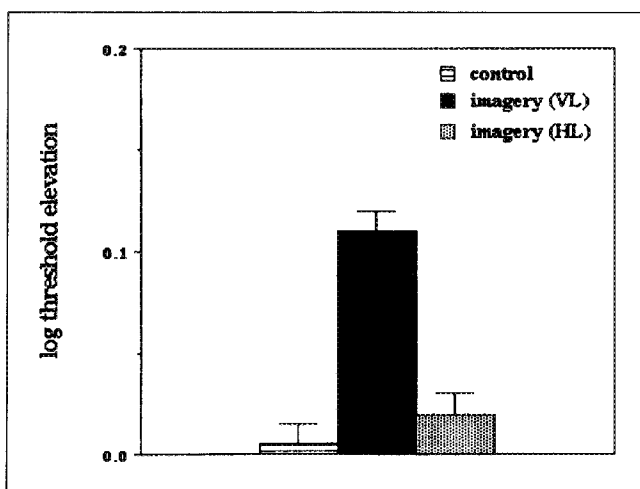
### Experiment 2: Short-Term Memory

To determine the role of short-term versus long-term memory in Perky effect, a new experimental procedure was introduced, in which observers had to detect a Gabor target with *vertical lines* superimposed on it in the perception condition and to imagine the lines in the imagery condition (Figure 3). In this procedure of alternating tasks, short-term memory was required to imagine the lines. As Figure 4 shows, the presence of the lines in the perceptual task increased target threshold, yet no interference was seen in the imagery task. Recall of vertical lines from short-term memory had no effect on

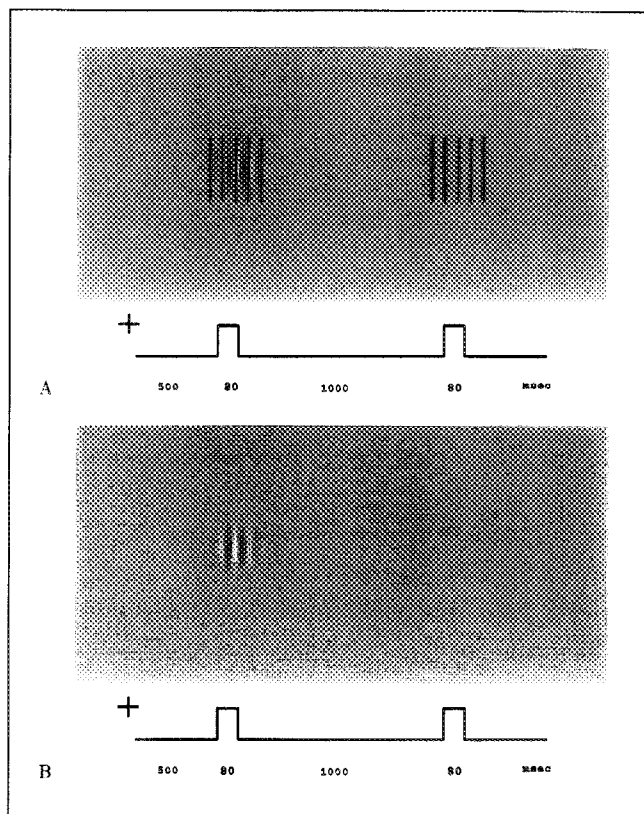


**Figure 1.** (A) Temporal sequence of a trial in long-term memory experiments. Observers had to detect a vertical foveal Gabor target in the control condition and had to detect the target while imagining vertical or horizontal lines (shown in B) in the imagery conditions. In this example the target appeared on the first presentation of stimuli. (B) Before the imagery experiments, observers were presented with examples of vertical and horizontal lines.

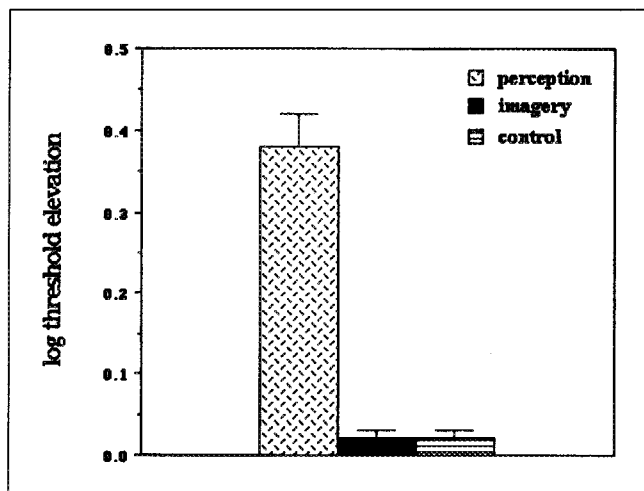
perception, as opposed to recall from long-term memory (Experiment 1). Furthermore, when *horizontal* lines were superimposed on a vertical Gabor target and observers had to imagine the absent horizontal lines, no effect on target threshold was seen—thresholds were  $0.03 \pm 0.01$  logarithmic unit in the perception condition,



**Figure 2.** Target threshold of a vertical Gabor signal in control, and imagery from *long-term memory* of vertical or horizontal lines, averaged across four observers (AI, IE, NK, and OY). Each bar, in this and subsequent histograms, represents the average of 20 blocks for each observer. Error bars, in this and subsequent graphs, indicate standard error of the observers mean (SE).



**Figure 3.** Temporal sequence of a trial in short-term memory experiments. (A) Vertical lines superimposed on a vertical Gabor target, used for the perception condition. (B) An isolated Gabor target used for the control and imagery conditions.



**Figure 4.** Target threshold of a vertical Gabor signal when vertical lines are superimposed on the target in the perception condition and vertical lines are imagined from *short-term memory* in the imagery condition, averaged across four observers (AI, IE, NK, and OY).

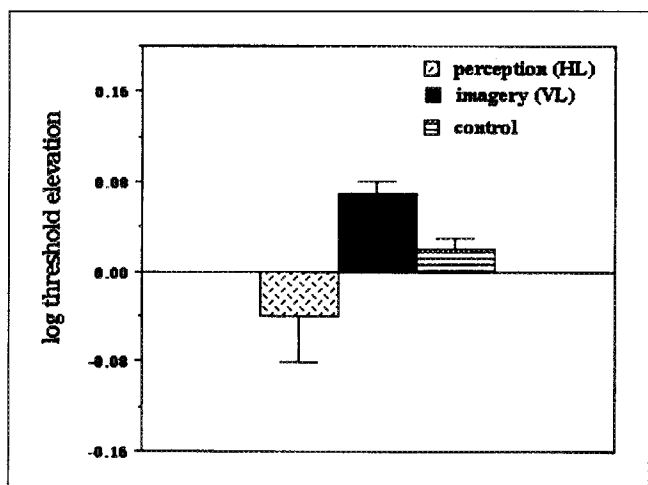
as compared with  $0.04 \pm 0.01$  and  $0.03 \pm 0.01$  in the imagery and control conditions, respectively (mean  $\pm$  SE,  $N = 20$  sessions, for observer IE). It seems that the suppressive effect of the imaginary lines on target threshold was due to image generation from long-term memory.

### Experiment 3: Interference Is Memory-Dependent

To compare between imagery tasks based on short- and long-term memory, the following experiment was designed: In the perception condition, observers detected a vertical Gabor target in the presence of *horizontal* lines; in the imagery task, observers were instructed to imagine *vertical* lines while detecting the target. In this procedure, there is a trace in short-term memory of the perceived horizontal lines, yet a recall from long-term memory is needed to imagine the vertical lines. As Figure 5 shows, imagery of vertical lines indeed interfered with perception. The differences between imagery and control conditions were statistically significant (repeated measures analysis of variance, followed by Scheffe multiple comparison,  $p < 0.05$ ). Note, however, that the imagery-induced interference in this experiment was smaller than the interference obtained in Experiment 1, probably due to the involvement of short-term memory. In light of these findings, it is reasonable to infer that imagery-induced interference is mediated by recall of common or familiar objects from *long-term memory*.

### Experiment 4: Additive Effects of Short- and Long-Term Memory

What is the nature of the memory trace? It is possible that the lines create an excitatory trace in short-term memory, balancing the inhibitory effect of recall from

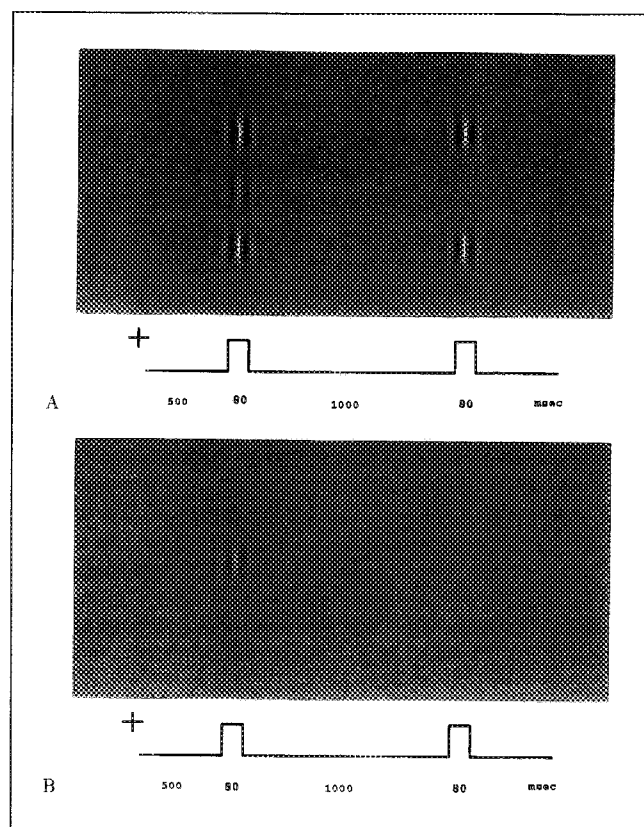


**Figure 5.** Target threshold of a vertical Gabor signal when *horizontal* lines are superimposed on the target in the perception condition and vertical lines are imagined from *long-term memory* in the imagery condition, averaged across four observers (AI, IE, NK, and OY).

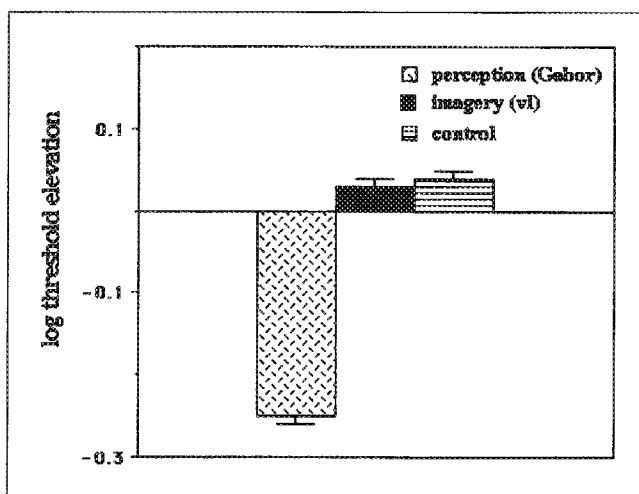
long-term memory; therefore no imagery-induced interference is seen (Experiment 2). Is this additivity specific for imaginary lines, or is it a general characteristic of visual memory systems? What would be the effect of imaginary lines, when the perceptual task is detection of a Gabor target flanked by Gabor masks at the optimal target-to-mask distance (see Figure 6)? Previously we have shown that presenting flanking masks at a distance of  $3\lambda$  created an excitatory trace that subserved an imagery-induced facilitation (Ishai & Sagi, 1995, 1997). Results answering these questions are shown in Figure 7. While the standard enhancement was obtained in the perception, imagery of vertical lines did not have a suppressive effect on target threshold, although the task required recall from long-term memory. The excitatory trace in short-term memory probably balanced the inhibitory effect of image generation from long-term memory, suggesting a mechanism of comparing and subtracting the present input from the representation in memory. The perceptual enhancement was based on similarity between the target and the flanking masks (not between the recalled image and the masks). When the perceptual task was detection of a vertical Gabor target flanked by *vertical lines* positioned at  $3\lambda$  and the following imagery task was to imagine the peripheral lines, neither facilitation nor suppression were seen; thresholds were  $0.02 \pm 0.02$  logarithmic unit in the perception condition,  $0.03 \pm 0.02$  in the imagery condition, and  $0.03 \pm 0.03$  in the control condition (mean  $\pm$  SE,  $N = 15$  sessions for observer AD).

### Experiment 5: Low-Level Representation

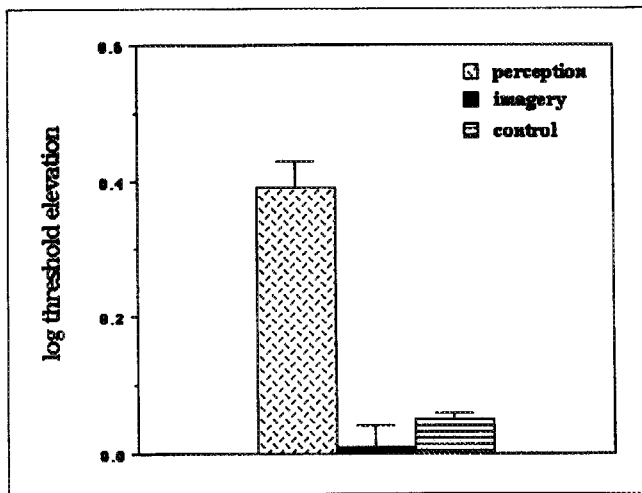
Is it possible to obtain a Perky effect, that is, an imagery-induced *interference*, with imaginary Gabor signal? Previously, we reported that imagining a Gabor signal on top of a Gabor target had no effect on target threshold (Ishai & Sagi, 1995, 1997). A plausible explanation was proposed in terms of interactions within the receptive field (Zenger & Sagi, 1996): Visual imagery could not mimic the suppressive effect of superimposing a real Gabor signal on the Gabor target. In an attempt to obtain an interference effect, we designed an experiment in which observers performed the detection task with the Gabor masks being superimposed on the target (i.e., a target-to-mask distance of  $0\lambda$ ). In the imagery task, observers were instructed to detect the target while projecting an image of the Gabor mask on top of the target. The experimental procedure was alternating tasks of perception followed by either control or imagery. As Figure 8 shows, neither interference nor facilitation were obtained, replicating the results of previous experiments (Ishai & Sagi, 1995, 1997). In light of these findings it is reasonable to infer that unlike lines, the representation of which in long-term memory can interfere with perception, the low-



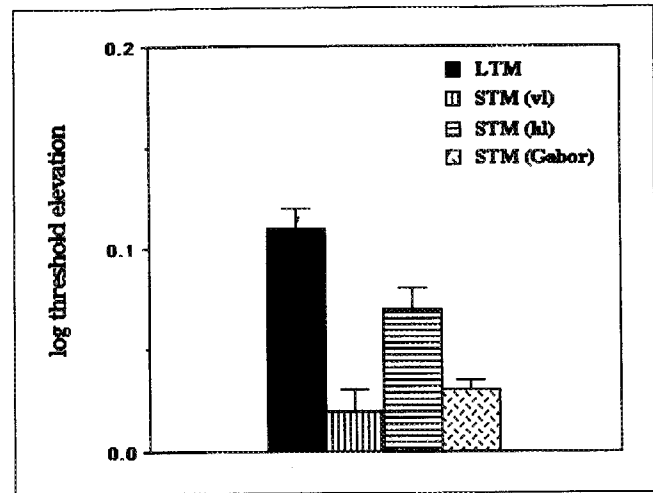
**Figure 6.** Temporal sequence of a trial in short-term memory experiments. (A) A foveal Gabor target flanked by two high-contrast Gabor masks, at a distance of  $3\lambda$ , used for the perception condition. (B) An isolated Gabor target used for the control and imagery conditions.



**Figure 7.** Target threshold of a vertical Gabor signal flanked by masks positioned at  $3\lambda$  in the perception condition and recall of *vertical lines* from long-term memory in the imagery condition for observer IE (mean  $\pm$  SE,  $N = 20$  blocks).



**Figure 8.** Target threshold in perception, imagery, and control conditions, averaged across two observers (EVS and NW). Data are presented for vertical target and masks. In the perception condition, observers had to detect the target when the mask was superimposed on it. In the imagery condition, observers imagined the absent mask.



**Figure 9.** Effects of imaginary vertical lines on target threshold of a vertical Gabor signal (summary of Experiments 1 through 5). Imagery-induced interference was maximal when lines were recalled from long-term memory. Excitatory trace in short-term memory (produced by either lines or Gabor stimuli) reduced the effect.

level representation of the Gabor signal is not sufficient to induce an interference effect.

It seems that indeed some mechanisms of comparing and subtracting the present input and the representation in long-term memory are involved. When an excitatory trace is created in short-term memory, the suppressive effect of recall from long-term memory is reduced (Experiments 2, 3, and 4). When the recall is based purely on long-term memory, the maximal interference is seen (Experiment 1). A summary of the results from the imaginary lines experiments is shown in Figure 9. These findings imply interactions between actual inputs and stored representations, which may subserve object recognition. Moreover, the differences between recall from long-term memory, as opposed to short-term memory, and the differences between lines and Gabor signals suggest that short-term visual memory maintains low-level descriptions, while long-term visual memory preserves structural descriptions.

## DISCUSSION

An imagery-induced interference (Perky effect) was obtained in a detection task of vertical Gabor signal only when observers imagined vertical lines on the target, using their long-term memory (Figures 2 and 4). No interference was obtained when observers imagined horizontal lines from long-term memory or Gabor signals and vertical lines based on short-term memory (Figures 2, 4, and 8). It is interesting to note that while the interference we obtained was orientation-specific (only imaginary vertical lines, not horizontal lines, affected

perception), Craver-Lemley and Reeves (1987) found that both imaginary vertical and horizontal lines, and even a gray mist, interfered with vernier acuity task (a decrease of 18, 19, and 12% of correct responses, respectively) as long as the image was projected on the target (Craver-Lemley & Reeves, 1987, Table 1). What is, then, the explanation for the difference between the orientation-specific interference in our experiments and the similar reduction in performance with imaginary vertical and horizontal lines in their experiments? While in our experimental procedure the task was detection of a *vertical* Gabor target, and hence vertical filters were needed to perform the task, in their acuity task horizontal filters were needed as well, in order for the observer to determine the offset of the vertical lines. When Craver-Lemley and Reeves (1987) compared the effect of *real* lines on the acuity task, they found that real vertical lines decrease accuracy but that real horizontal lines do not. Interestingly, in our experiments real horizontal lines did not interfere with detection of a vertical Gabor target either, as opposed to a large interference seen with real vertical lines (see Figures 4 and 5). Craver-Lemley and Reeves (1987) concluded that "visual imagery produces a spatially and temporally local reduction in sensitivity, perhaps at a level prior to the extraction of stimulus features such as orientation." The orientation-specific interference reported here is probably due to inhibition of oriented filters. These results may indicate processing at the level of the primary visual cortex or above, where cells are tuned to the orientation of the stimulus.

The differences between lines and Gabor signals, as well as recall from long-term as opposed to short-term

memory (see Figures 2, 4, 5, and 7), support the idea of two types of representation in visual memory. Visual short-term memory is seen as a limited-capacity system that maintains a record of recently presented visual information. Long-term memory is a more durable store for well-learned information, with no obvious limit on its storage capacity. A similar distinction appears in Kosslyn's (1980) theory of visual imagery, according to which visual images are maintained by using a limited-capacity short-term visual buffer. Images can be generated from stored information in visual long-term memory or can be formed directly from perception, as a record of recent visual experience (in our experiments the imagery task was based on a recent perceptual task). Baddeley's (1986) model of working memory takes a similar position with its assumption that a limited-capacity store, known as the *visuospatial sketchpad*, is used for constructing and maintaining visual images. A basic requirement of any theoretical account of visual memory is to specify the different kinds of information that can be represented in memory and the conditions under which these memory representations are utilized. Within the domain of *verbal* memory, it is believed that words are stored in short-term memory in terms of their acoustic or phonological properties, whereas in long-term memory words are stored in terms of their meaning (Baddeley, 1966a, 1966b). Is there an analogous distinction within the domain of visual memory? Researchers have proposed that visual short-term memory concerns the surface appearance of objects, whereas visual long-term memory involves the abstract, structural descriptions of objects (Humphreys & Bruce, 1989). Alternatively, it has been proposed that long-term memory stores surface as well as abstract descriptions (Kosslyn, 1980). Another view is that visual short- and long-term memory are indistinguishable in terms of the representation they use (Phillips, 1983).

Hitch, Brandimonte, and Walker (1995) used an imagery task to explore the distinction between visual memory representations. In their experiments, subjects were shown two line drawings and were then asked to combine a visual image of each drawing in order to identify a novel figure. Image combination was more efficient when the contrasts of the two drawings were congruent with each other, but only when the imagery task was performed under conditions emphasizing short-term memory. There was no effect of congruity when one of the images was generated from long-term memory. The authors suggested that short-term visual memory maintains surface features (such as contrast), and long-term visual memory preserves both surface and abstract descriptions. Since verbal coding improved performance of the imagery task under long-term memory, they concluded that "verbal coding of visual stimuli appears to encourage the use of abstract visual descriptions" (Hitch et al., 1995).

In our experiments, imaginary Gabor signals facilitated

perception only under short-term memory conditions, while imaginary vertical lines interfered with perception only under long-term memory conditions. These results support the distinction between low-level representation (Gabor) in short-term visual memory and structural (lines) description in long-term visual memory. Marr (1982) has proposed the distinction in the context of object recognition as follows: A surface description of an object specifies its appearance under a particular set of viewing conditions. The structural description specifies the shape, position, and orientation of an object, independent of the conditions under which the object is viewed. In order to recognize objects, the visual system has to cope with changes in surface characteristics when parameters such as illumination, size, and orientation alter. It seems that the interface between perception, recognition, and memory involves some mechanisms of subtracting the actual input from the stored input (see Figure 9). When recall from long-term memory is required, in the absence of real input, the net effect is interference. When the task is based on short-term memory, the excitatory trace is subtracted from the inhibitory trace of long-term memory; hence the result is less interference, and even facilitation. Thus, both imagery-induced facilitation and interference are memory dependent.

## METHODS

### Apparatus

In Experiment 1, stimuli were displayed as gray-level modulation on an Hitachi HM-3619A color monitor, using an Adage 3000 raster display system. The video format was 56 Hz noninterlaced, with  $512 \times 512$  pixels occupying a  $9.6 \times 9.6^\circ$  area, each at 8 bits. The mean display luminance was  $40 \text{ cd/m}^2$ . Stimulus generation was controlled by a Sun-3/140 workstation and the stimulus display was controlled by the Adage local processor. Gamma correction was applied using 10-bit lookup tables and digital-to-analog converters (DACs).

In Experiments 2 through 5, stimuli were displayed as gray-level modulation on a Mitsubishi color monitor, using a Silicon Graphics Reality Engine system. The video format was 60 Hz noninterlaced, with  $1280 \times 1024$  pixels occupying a  $13 \times 10.4^\circ$  area. A 12-bit RGB mode was used, in which 12-bit pixels were converted by dithering into 10-bit values and then by a 10-bit gamma correction into 8-bit RGB DACs. The mean display luminance was  $40 \text{ cd/m}^2$ . Stimulus generation and display were controlled by a SGI Crimson/Reality Engine workstation.

### Stimuli

Stimuli consisted of three Gabor signals arranged vertically. A Gabor function is defined by:

$$G(x, y|x_0, y_0) = \cos \left\{ \frac{2\pi}{\lambda} [(x - x_0) \cos \theta + (y - y_0) \sin \theta] \right\} \exp \left[ - \left( \frac{(x - x_0)^2 + (y - y_0)^2}{\sigma^2} \right) \right]$$

and the stimulus is defined by:

$$I(x, y) = I_0 + A_{m1}G(x, y|x_0, y_0 + D) + A_tG(x, y|x_0, y_0) + A_{m2}G(x, y|x_0, y_0 - D)$$

where  $x_0$  and  $y_0$  represent the center of the Gabor signal,  $x$  and  $y$  are the coordinates over the Gabor's domain,  $\theta$  is the orientation (in radians),  $\lambda$  is the wavelength, and  $\sigma$  is the standard deviation of the Gaussian envelope.  $A_t$  and  $A_{m1}$ ,  $A_{m2}$  are the target and masks amplitudes, respectively. In all experiments mask amplitude was 40% of mean luminance, with  $\lambda = \sigma = 0.15^\circ$ , and  $I_0 = 40$  cd/m<sup>2</sup>.

### Experimental Procedures

A two-alternative-forced choice paradigm was used. Each trial consisted of two stimuli presented sequentially, only one of which had a target. Before each trial, a small fixation cross was presented at the center of the screen. When ready, the observer pressed a key activating the trial sequence: a no-stimulus interval (0.5 sec), a first stimulus presentation (80 msec), a no-stimulus interval (1 sec), and a second stimulus presentation (80 msec). In Experiment 1 the stimulus presentation was 90 msec (see Figure 1). The observer was asked to perform a detection task, that is, to determine which of the stimuli contained the target.

Each block consisted of 50 trials on average, across which the distance between the Gabor signals was kept constant. Screen luminance ( $I$ ) was kept constant during the trials. The stimuli were viewed binocularly from a distance of 150 cm in a dark environment. Auditory feedback, by means of a keyboard bell, was given immediately after an erroneous response.

In long-term memory experiments, two experimental conditions were used: (1) a *control* condition, in which the observer detected a vertical Gabor target and (2) an *imagery* condition, in which the observer was instructed to imagine either vertical or horizontal lines while detecting the Gabor target. Each session included 10 blocks.

In short-term memory experiments, three experimental conditions were used: (1) a *perception* condition, in which the observer detected the target in the presence of the vertical or horizontal lines or in the presence of flanking Gabor masks, (2) a *control* condition, in which the observer detected the target in the absence of the lines or flanking masks, and (3) an *imagery* condition, in which the observer was instructed to imagine the absent lines while detecting the isolated target. Each session included eight alternating blocks of either percep-

tion followed by control or perception followed by imagery.

Target threshold contrast (which ranged from 5 to 15%) was determined by a staircase method, which was shown to converge to 79% correct (Levitt, 1971). In this method, the number of threshold contrast reversals within each block was counted, and the block was terminated after eight such reversals; hence the number of trials in a single block was not constant. Threshold contrast of a block was the averaged value of the last six reversals (the first two were ignored). A reversal was either an erroneous response, which led to an increase of 0.1 logarithmic unit ( $\sim 26\%$ ) in target threshold, or three consecutive correct responses, which led to a decrease of 0.1 logarithmic unit in target threshold. The threshold was computed relative to detection of the isolated target in the presence of two peripheral high-contrast crosses, occupying  $1^\circ$  of the visual field, placed at the top and bottom of the display (eccentricity of  $4^\circ$  from the foveal target). The baseline threshold was measured twice in each session (the first and last blocks).

### Observers

Five observers (EVS, IE, NK, NW, and OY) and one of the authors (AD) participated in the experiments. The observers, high school and undergraduate students (between the ages of 16 and 25), were naive as to the purpose of the experiments and were paid in return. All observers had normal or corrected-to-normal vision.

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